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(54) Borehole pressure and temperature measurement system.

(57) A system is provided for measuring both the temperature and pressure of fluid in a borehole utilizing a single small diameter tube extending from the surface to the desired downhole test location in a borehole. Downhole fluid pressure is transmitted through the small diameter tube, while a sheathed thermocouple or fibre optic line extending along the flow path of the tube is used for transmitting downhole fluid temperature information to the surface. A continuous surface read-out of both pressure and temperature is thus possible, and the temperature read-out may be used to both monitor downhole fluid temperature and increase the accuracy of the fluid pressure measurement system.

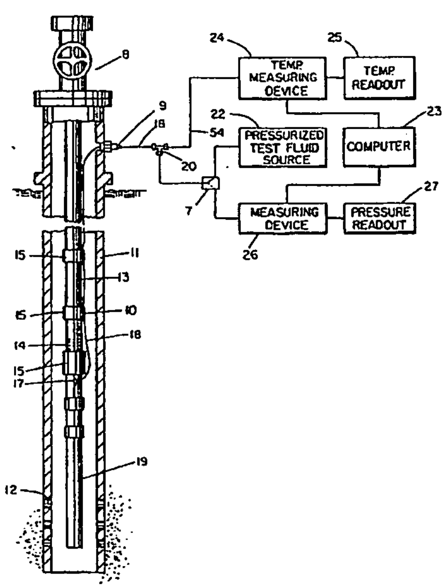

FIG. 1

BOREHOLE PRESSURE AND TEMPERATURE MEASUREMENT SYSTEM

The present invention relates to techniques for monitoring temperature and pressure in a remote and hostile environment. More particularly, the present invention is directed to reliably measuring downhole fluid pressure and temperature within a borehole of an oil, gas, or geothermal well.

The accurate measurement of downhole fluid pressure and temperature in a borehole has long been recognized as being important in the production of oil, gas, and/or geothermal energy. Accurate pressure and temperature measurements typically indicate a number of problems in pumping wells which are commonly used in oil recovery operations. Both secondary hydrocarbon recovery operations and geothermal operations typically require pressure and temperature information to determine various factors considered useful in predicting the success of the operation, and in obtaining the maximum recovery of energy from the borehole.

In secondary hydrocarbon recovery operations, accurate borehole pressures specifically give an indication of well productivity potential, and allow the operator to predict the amount of fluid that should be required to fill the formation before oil or gas can be expected to be forced out from the formation into the borehole and then recovered to the surface. The accurate measurement of pressure and temperature changes in well fluids from each of various boreholes extending into a formation may indicate the location of injection fluid fronts, as well as the efficiency with which the fluid front is sweeping the formation. In geothermal wells, accurate pressure and temperature information is critical to efficient production due to the potential damage which occurs if reinjected fluids cool the formation or changes in fluid dynamics cause well bore plugging.

Techniques have been devised for providing a periodic measurement of downhole conditions by lowering sensors into tee borehole at desired times, although such periodic measurement techniques are both inconvenient and expensive due to the time and expense normally required to insert instrumentation into the borehole. Any such periodic measurement technique is limited in that it provides only a representation of borehole conditions at specific times, and does not provide the desired information over a substantial length of time which is typically desired by the operator. An example of this type of system is disclosed in U.S. Patent 3,712,192, which teaches charging an open-ended tube with a gas until it bubbles from the bottom of the tube in order to provide the desired periodic pressure measurement.

Permanent installation techniques have been devised for continually monitoring pressure in a borehole in a manner which overcomes the inherent problems associated with periodic measurement. One such prior art technique employs a downhole pressure tranducer and a temperature sensor having electronic scanning ability for converting detected downhole pressures and temperatures into electronic data, which then are transmitted to the surface on a conductor line. The conductor line is normally attached to the outside of the tubing in the wellbore, and the transducer and temperature sensor are conveniently mounted on the lower end of the production tubing. This system has not, however, been widely accepted in the industry, in part because of the expense and high maintenance required for the electronics positioned in the hostile wellbore environment over an extended period of time. The high temperatures, pressures and/or corrosive fluids in the wellbore thus substantially increase the expense and decrease the reliability of the downhole electronics. Downhole pressure transducers and temperature sensors which output electronic data for transmission to the surface are generally considered delicate systems, and thus are not favored in the hostile senvironments which normally accompany a downhole wellbore.

U.S. Patent 3,895,527 discloses a system for remotely measuring pressure in a borehole which utilizes a small diameter tube which has one end exposed to borehole pressure and has it other end connected to a pressure guage or other detector at the surface. The concept of measuring downhole pressure according to a system which uses such a small diameter tube is also disclosed in U.S. Patent 3,898,877, and an improved version of such a system is disclosed in U.S. Patent 4,010,642. The teachings of this latter patent have rendered this technology particularly well suited for more reliably measuring pressure in a borehole, since the lower end of the tube extends into a chamber having at least a desired volume which satisfies the relationships expressed in the '642 patent.

Although the techniques disclosed in the '642 patent have been accepted in the energy recovery industry, the teachings of this patent do not enable the detection of both downhole temperature and pressure at the desired location within the borehole. In general, an operator may estimate downhole fluid temperature by either extrapolating from assumed temperature gradient data and temperature measurements taken at the surface, and/or by estimating an average temperature for the borehole from previously obtained drilling data. This estimated temperature may then be used to determine a test fluid correction factor, which may then applied to more accurately determined downhole pressure. Those skilled in the art

have long recognized, however, that accurate temperature information is not being obtained, and that the correction of pressure readings based on such inaccurate temperature estimates accordingly results in errors in the pressure readings obtained by the technique of utilizing such a small diameter tube.

The estimated temperature is not only inaccurate, thereby resulting in erroneous well bore pressure data, but the actual temperature within a well varies considerably as a function of both well bore depth and conditions such as water flashing, gas release and/or "freezing" which may occur at particular depths. The result is that the operator cannot reliably and economically measure well bore temperature or pressure in most boreholes, and accordingly thee operator cannot maximize recovery of energy from the borehole.

The disadvantages of the prior art are overcome by the present invention, and improved methods and apparatus are hereinafter disclosed for reliably detecting both pressure and temperature in a wellbore utilizing a single small diameter tubing extending from the surface of the well to the desired downhole test location.

The pressure and temperature measurement system of the present invention is particularly well suited for use in oil, gas and geothermal wells. A small diameter tube extends from the surface to the desired downhole test location, and houses a sheathed thermocouple or fibre optic which similarly extends from the surface to the downhole location for accurately relating downhole temperature measurements. A housing is lowered in the well to the test location, and includes a chamber which is open to both downhole fluids and the flow path in the tube. The tube and a portion of the chamber are filled with a selected fluid, and borehole fluid pressure fluctuations are thereby transmitted to the surface via the fluid in the annular space between the interior diameter of the tubing and the thermocouple or fibre optic line. Borehole temperature measurements may be taken at the surface by monitoring the electromotive force across the thermocouple, which is transmitted via the line to the surface for read-out. Alternatively, a well bore temperature profile may be obtained from temperature measurements at periodic, e.g., one meter, intervals utilizing a fibre optic line within the small diameter tube. Both pressure and temperature monitoring and plotting devices may be provided at the surface, and the temperature sensing instrumentation is preferably used to determine a more accurate downhole pressure reading.

It is object of the present invention to continuously provide reliable downhole temperature and pressure information to the surface of a well utilizing a single tube extending from the surface to the downhole test location and a thermocouple or fibre optic line within the interior of the tube.

It is a further object of the invention that the thermocouple or fibre optic line extending from the surface to the downhole test location be protected in part by the test fluid in the tube, which test fluid is less hostile than the fluids otherwise in the wellbore.

It is a feature of the invention that both downhole fluid temperature and pressure may be continuously monitored without utilizing any electrojunctions within in either the borehole or the wellhead.

It is also a feature of the present invention that a reliable wellbore temperature profile may be obtained utilizing a single fibre optic loop within a small diameter tube extending from the surface to a downhole location.

It is an advantage of the invention that multiple lines need not extend from the surface to the downhole test location in order to reliably monitor both fluctuating well fluid pressure and temperature.

Yet a further advantage of this invention is that fibre optic surface equipment may be used to receive signals from multiple fibre optic loops each protected within its own small diameter pressure tube and preferably extending into different well bores.

These and further objects, features, and advantages of the present invention will become apparent from the following detailed description, wherein references made to the figures in the accompanying drawings.

Figure 1 is a pictorial view, partially in cross-section, of the pressure and temperature monitoring system according to the present invention in a wellbore of a producing hydrocarbon recovery well.

Figure 1A is a simplified pictorial view, partially in cross-section, of a portion of the pressure and temperature monitoring system shown in Figure 1.

Figure 2 is a detailed cross-sectional view of a suitable downhole portion of the pressure and temperature monitoring system suspended in a wellbore from a small diameter tubing.

Figure 3 is a detailed cross-sectional view of suitable surface manifold for separating the pressurized test fluid and the thermocouple or fibre optic line so that both pressure and temperature can be monitored by suitable surface equipment.

Figure 4 is simplified pictorial view of a suitable technique for installing a thermocouple or fibre optic line in a test tube in accordance with the present invention.

Figure 5 is a simplified pictorial and block diagram illustration of the surface components of the fibre optic system according to this invention for accurately determining downhole pressure and temperature.

The present invention has utility for reliably monitoring downhole fluid pressure and temperature in a oil,

gas or geothermal well. For purposes of the present invention, the downhole fluid to be monitored is presumed to be at a depth in the well of at least 1,000 feet, and typically would be several thousand feet or more below the surface. The fluctuating downhole fluid pressure to be monitored is typically less than normal hydrostatic pressure, although this downhole fluid pressure may be monitored in flowing, pumping or static wells, and the downhole fluid may be equal or greater than hydrostatic pressure.

Figure 1 illustrates a typical wellbore extending into underground formation. Figure 1 illustrates a producing well, and thus production equipment including a conventional wellhead 8 is shown generally at the surface. A casing 11 is positioned in the wellbore, and has perforations 12 at its lower end to permit the entry of fluid from the formation into the casing 11. Production tubing string 13 extends from the wellhead at the surface to a selected depth in the borehole. A perforated protion 14 of the tubing string 13 allows fluid in the casing 11 to enter the production tubing and then to flow to the surface. Collar protectors 15 are provided along the tubing string 13 to secure a small diameter continuous tubing 18 to the tubing string 13 and thus assist in protecting the small diameter tubing in the borehole. A housing 19 is provided at the lower end of the production tubing 13, and includes a chamber 16 having ports for maintaining fluid communciation between the chamber and the fluid in the wellbore outside the housing 19.

The small diameter tube 18 in accordance with the present invention extends from the surface to the test location where housing 19 is located. The tubing 18 may enter a lower portion of the production tubing 13 at entry port 17, then continue downward into the housing 19 so that the lower end of the tubing 18 is in fluid communication with the chamber 16. Suitable small diameter tubing according to the present invention may have an 0.250" outer diameter and an 0.18" internal diameter. A thermocouple line may be provided within the tube, and this thermocouple line would typically have a cross-sectional area from about 25% to about 50% of the cross-sectional area of the flow path in the tube. A fibre optic line, discussed in detail subsequently, may be used instead of a thermocouple line, and in this case the temperature measuring line would typically have a cross-sectional area from about 10% to about 50% of the cross-sectional area of the flow path in the tube. As those skilled in the art appreciate, small diameter tubing in the range as specified above is commonly referred to as microtubing.

Figure 1 also indicates that the tube 18 extends to the surface of the well and exits on the side of the well at fitting 9. Manifold 20 provided for sealing around the tube and allowing the thermocouple or fibre optic line to exit the manifold. The thermocouple or fibre optic line at the surface is designated as 54, and continues to temperature measuring equipment 24, with its ouput fed to temperature readout 25. The manifold has a fluid exit port that effectively provides for a continuation of the tube to a valve 7, which in turn may be connected by one line to a pressurized fluid source 22, and by another line to a pressure measuring device 26, with its output fed to pressure readout 27. It should be understood that the temperature measurement and readout devices may be provided separate from or as part of the pressure measuring device 26 and readout 27. In either event, however, the output from the temperature measuring device 24 is preferably input to computer 23, which then provides a pressure correction value to device 26, as explained subsequently.

Referring now to Figure 1A, the lower end of the housing 19 has entry ports 39 which establish fluid communication between the chamber 16 and wellbore, while the upper end of the chamber 16 is in fluid communication with the tubing 18. The thermocouple or fibre optic line 21 extends from the end of the tubing 18 into the chamber 16, and is preferably positioned in the chamber at a location below the test fluid and thus in contact with the borehole fluid. A filter assembly 36 may be fabricated from a porous metal material or small mesh screen and prevent solids from communicating between the chamber 16 of the tube 18. Tubing 18 may be physically connected to a top plug fitting 34 by assembly 28, which also provides a fluid-tight seal between the tubing 18 and the fitting 34. A second or backup assembly 29 similarly provides a connection between the lower end of the fitting 34 and the tubing 18. Tubing 18 may terminate immediately below the assembly 29, although the thermocouple or fibre optic line 21 preferably extends downward into engagement with the well fluid. If a thermocouple line is utilized, the thermocouple junction 38 is directly in the downhole fluid and thus responsive to its fluctuating temperature. If a fibre optic line is utilized, temperature measurements at regular intervals, e.g. one meter intervals, may be obtained at each test site from the surface to the pressure test housing 19. A complete temperature profile of the well bore as a function of depth may be generated with the fibre optic system, since the temperature of the fluid in the tubing 18 at any location may be obtained, and the temperature acting on the fibre optic line at that location will approximately match the changing temperature of the well fluids in the borehole at that location. Nevertheless, the lowermost end of the fibre optic line preferably extends into engagement with the well fluid, so that a more accurate measurement of well fluid temperature within the housing 19 is obtained. The system as shown in Figures 1 and 1A may therefore be characterized as a semi permanent measurement system, since the downhole components and the tubing 18 would remain connected to the production

tubing 13 until the production tubing was returned to the surface.

Figure 2 depicts an alternate embodiment of the lower portion of the pressure and temperature monitoring system, which may be lowered into a wellbore from the small diameter continuous tubing 18 rather than from production tubing. In this embodiment, the downhole equipment thus consists of a top shroud 33 for receiving the small diameter tubing 18. Shroud 33 has lower threads for engagement with top plug fitting 34, which has cylindrical interior passageway for receiving the tubing 18. Fitting 34 is threadably connected to housing 19 by threads 40, and sealed engagement between these bodies is provided by a suitable O-ring seal 42.

Figure 2 depicts in detail assembly 28 for mechanically connecting tubing 18 and fitting 34. Member 46 may be threaded at 44 to fitting 34, and includes a cylindrical interior passageway aligned with the passageway in the fitting 34. A top cap 48 may be threaded to member 46, and torqued rotation of 48 relative to 46 causes the interior cylindrical surface of ferrule 45 to sealing grasp the tubing 18 in a conventional manner. A similar member 47 is shown for the second or backup assembly 29, and includes a corresponding cap 49 for threaded engagement with 47 and thus similarly grasp the tubing 18. The shroud 33 physically protects the upper assembly 28, and a sleeve-like extension 35 may be threaded to the top plug fitting 34 and similarly form a protective housing for the lower assembly 29. A filter assembly 36 as described above may be threadably connected to the lower end of sleeve 35, and keeps solid debris in the well fluids from entering the interior of tubing 18. The thermocouple or fibre optic line 21 preferably extends downward past the filter 36. If a thermocouple line is used, the thermocouple measuring junction 38 is thus in fluid communication with the downhole well fluids. If a fibre optic line is used, no thermocouple junction is required, and the fibre optic line itself is exposed to the downhole well fluids to cause a change in the transmitted laser pulse as a function of temperature.

The apparatus as shown in Figure 2 is accordingly adapted for being suspended in the wellbore solely from the tubing 18. Accordingly, this embodiment is particularly well suited for measuring downhole tubing temperature and pressure in geothermal wells where no production tubing is typically utilized. Those skilled in the art will appreciate, however, that the upper portion of the apparatus as shown in Figure 2 may be easily altered so that the downhole assembly can be secured from the lower end of production tubing, as generally shown in Figure 1A, in which case the small diameter tubing 18 could then pass into interior of the production string at a suitable port 17 provided therein.

According to the present invention, the volume of the chamber 16 must be sufficiently large to accommodate the minimum and maximum pressure anticipated in the well bore. The required volume of this chamber is based in part on the volume of the flow path in the tube, and thus takes into consideration the interior cross-sectional area of the tubing 18, the length of the tubing 18, and the cross-sectional area of the line 21.

The downhole chamber 16 thus has at least preselected volume as set forth in U.S. Patent 4,010,642. This minimum chamber volume is based on the volume of test fluid in the tube, the chamber volume may be significantly reduced by the inclusion of the line 21 within the tube. Accordingly, the minimum chamber volume according to the present invention is based on the cross-sectional area of the annulus between the internal diameter of the tube and the external diameter of the thermocouple or fibre optic line in the tube rather than the interior cross-sectional area of the tube itself. Further details with respect to the minimal volume of the chamber 16 are disclosed in the U.S. Patent 4,010,642, which is hereby incorporated by reference.

In operation, the small diameter tubing 18 with the thermocouple or fibre optic line positioned therein is secured to the housing 19, as illustrated in Figure 1A or Figure 2. The housing 19 and tubing 18 are then lowered to the desired test location in the wellbore, and valve 7 is manipulated so that the tubing 18 is filled with a desired test fluid from source 22 at the surface. Once the desired test fluid/downhole fluid interface within the chamber 16 is obtained, valve 7 may be manipulated to shutoff the test fluid source 22 while simultaneously allowing the pressure measuring device 26 to be responsive to test fluid pressure at the surface in the tubing 18. Fluid temperature and pressure may be maintained continuously with the downhole apparatus remaining at the same depth for the semipermanent installation equipment as shown in Figure 1 and 1A, or may be monitored at various selected depths over a period of time during which the downhole equipment as shown in Figure 2 is raised or lowered through the borehole.

Various types of test fluids may be used for filling the interior of the tube 18 and a portion of the chamber 16, provided the thermal compressability characteristics of the fluid are known. Both nitrogen and helium have been found particularly suitable as a test fluid, in part because the compressability factor, sometimes referred to as the "Z factor", for each of these fluids is well known in the range of commonly encountered downhole fluid pressures and temperatures.

Those skilled in the art will now appreciate that, if a thermocouple line is placed within the tubing 18

and the tubing placed into service as explained above, the temperature of the well fluid at the desired test location in the borehole can be easily and reliably monitored by surface equipment which measures the electromotive force created by the thermocouple junction. The thermocouple line thus transmits this indication of temperature from the thermocouple junction 38 in contact with the well fluid to the measuring device 24 at the surface. If desired, these temperature readings can be conveniently output at 25 and maintained on any number of suitable recording means.

Alternatively a fibre optic line may be placed within the tubing 18 and the tubing placed into service. In this case, the temperature of the fluid within the tubing, and thus the approximate temperature of the well fluid outside the tubing, may be measured at regular intervals, such that a complete well bore temperature profile is obtâined. The fibre optic system relies upon the concept that the local light scattering power of a fibre core depends on the fibre temperature, and this relationship is well understood to those skilled in fibre optic temperature measurement systems. A suitable fibre optic system for the present invention is the DTS System II distributed by York V.S.U.P. sales in Burbank, California. A laser pulse is launched into the sensor fibre and travels along the fibre at a constant speed. As it travels along the fibre, the pulse interacts with a silica and dopant matrix, causing some energy to be scattered in all directions. Some of the light will effectively be reflected and travel back toward the source on the surface, where it can be diverted to the detector by a fibre optic coupler. The amount of power to the detector at a specific time is measured to determine the temperature of the fibre at a specific depth, since the distance from the source to the reflected location along the fibre is a direct function of the constant laser pulse velocity and time. In this case, the temperature measuring device 24 at the surface may be the sensor system commercially available from York, including an optical front end, timer, A/D converter, amplifier and microprocesser.

An optical system capable of measuring temperature at every one meter intervals and extending to a depth of 1000 meters should be capable of an accuracy of less than 1C°. If desired, optical system surface equipment 24 and 25 may be used for multiple optical lines each extending.within a different fluid tube positioned in a nearby well. The easily obtained temperature profile may be used to not only obtain more accurate well bore pressure measurements, as more fully explained hereafter, but also may indicate significant temperature-related wellbore conditions. In a geothermal well, for example, the optical system temperature profile may indicate depths where superheated water flashes to steam, thereby providing an early indication where scaling may form that may could change the well. In petroleum wells, the generated temperature profile may indicate locations where gas is coming out of solution, which impacts the performance of the well. In a natural gas well, this temperature profile may indicate a depth at which "freezing" is likely to occur, which could stop production if left uncorrected.

The temperature readings as obtained above can also be used to more reliably determine the accurate downhole fluid pressure. Those skilled in the art appreciate that the actual downhole fluid pressure is a function of the pressure measured at the surface and the hydrostatic pressure of the test fluid passing from the surface to the downhole test location. The hydrostatic head of a test fluid, in turn, is a function of the vertical depth from the surface to the downhole test location, and the gas gradiant of the test fluid. The true verticle depth for determining the hydrostatic pressure of the test fluid is generally known or can be easily determined by conventional methods. The gas gradiant for the test fluid can be determined by the following formula:

$$\text{Gas Gradiant} = \frac{(\text{Specific Gravity}) \times (\text{Approx. Average Pressure})}{(\text{Z Factor}) \times (\text{Average Temperature})}$$

The above formula thus requires the average temperature of the test fluid be known, and the techniques of the present invention can be easily used to monitor the downhole temperature of the test fluid and thereby more accurately determine the average temperature of the test fluid and thus determine the correct gas gradiant. The specific gravity of the test fluid, as well as the Z factor, can be determined with sufficient accuracy from the uncorrected or approximate test fluid pressure readings and the test fluid temperature readings. The addition of the thermocouple line within the small diameter tubing allows for accurate temperature measurements of the downhole fluid and thus more accurate average test fluid temperature determinations. The use of the fibre optic line within the small diameter tubing allows for accurate temperature measurements of both the downhole fluid at the location of housing 19 and the well bore fluid at each incremental depth in the wellbore. A significant advantage of the fibre optic temperature measurement system is that a single small diameter tubing with a fibre optic line therein may be used to generate a complete well bore temperature profile. With this temperature profile, highly accurate average test fluid

temperature determinations can be made, thereby resulting in more accurate downhole pressure measurements. Significantly more accurate and yet continuous pressure measurements of the well fluid may thus be determined in real time in accordance with the present invention.

Figure 3 depicts a suitable manifold conveniently located at the surface apart from the wellhead for separating the thermocouple or fibre optic line and the pressurized test fluid. The T-shaped body is provided with an input port for receiving the tubing 18 and the thermocouple or fibre optic line interior thereof, an output port in fluid communication with the tubing for passing pressure readings to measuring device 26, and an output port for transmitting the thermocouple or fibre optic line to the temperature measuring device 24 while sealing the test fluid within the body 56.

Three identical end caps 58 may be provided at each of the ports. End cap 58 may be threaded to the body 56 at the input port to force ferrule 60 into gripping and sealed engagement with the outer cylindrical surface 52 of the tubing 18. Similarly, the end cap 58 may be provided at the pressure output port of the manifold 20 for enabling the test fluid be transmitted outside of the manifold 20 and to the measuring device 26. Fitting 64 having a sleeve-shaped portion 66 structurally similar to tube 18 may be connected to the body 56 by end cap 58. The end of fitting 64 outside the body 56 has a cylindrical passageway closely approximating the outer diameter of the thermocouple or fibre optic line 54, which extends to the temperature measuring device 24. Line 54 may be sealed to the fitting 64 by another end cap 62 and ferrule 68. While the design and construction of the manifold 20 are not critical to the present invention, it is a significant feature of the present invention that the manifold can be located at the surface at a location separate from the wellhead 8.

The small diameter tube 18 according to the present invention preferably has an internal diameter of less than approximately 0.21 inches. In order to accommodate the thermocouple line, this interior diameter should be greater than about 0.10 inches. The effective volume of the tube, and thus its cross-sectional area, should follow the guidelines set forth in U.S. Patent 4,010,642. The thermocouple line, if utilized, includes two dissimilar metal conductors, which have high reliability due to the combination of the protection afforded by the non-hostile environment created by the test fluid in the tube 18 which surrounds the thermocouple line, and the physical protection afforded by the structure shown in Figure 4. This physical structure may be relatively inexpensive compared to thermocouple lines which would otherwise extend Into a borehole, due to the non-hostile environment in which this thermocouple line is placed in accordance with the present invention. The two dissimilar metal conductors are joined to form a thermocouple junction which is located within the chamber in the housing 19 to measure downhole fluid temperature, either by being in engagement with that fluid, or by being positioned in the test fluid immediately above the downhole fluid. The latter situation will thus result in a slower responsive time to detect fluctuating downhole fluid temperature.

In the fibre optic line embodiment, the two optical fibers in the line are the halves of a single fibre optic loop, with both ends of the loop being at the surface and the middle section of the loop being within the housing 19. Again, high reliability and reduced coating costs for the fibre optic loop are obtained as a result of the non-hostile environment created by the test fluid in the tube 18 which surrounds the fibre optic line. The cost of the fibre optic system per foot approximates the cost of a thermocouple system, although multiple temperature points are measured. The tube 18 not only reduces the cost of the coating which may be applied over the fibre optic line, but also overcomes significant limitations of a fibre optic temperature measurement system in a well bore unprotected by such a tube, in that the fibre optic line itself is typically too light and flexible to withstand flow velocity in a dynamic well. While a fibre optic line could possibly be weighted to minimize this difficulty, the increased weight may exceed the recommended strength of the optical fibre line if used in a deep well. By enclosing the fibre optic line in tube 18, the line is protected in a non-hostile and essentially static environment, which also satisfies the wellbore pressure measurement concept of this invention.

Since the downhole fluid to be measured by the present invention may be a 1,000 feet or more below the surface, it would be difficult if not impossible to insert the thermocouple or fibre optic into the small diameter tubing after the tubing was manufactured. While such insertion might be possible for a larger diameter tubing, the small diameter of the tubing 18 and its associated low cost and low volume are significant features of the invention. Accordingly, the thermocouple or fibre optic line 21 is preferably inserted into the tubing 18 as the tubing is fabricated. Figure 4 depicts a flat sheet metal stock 17 used to form the tubing, which may be bent by suitable extrusion dies (not depicted) to form a tubular member. The tubing is then completed by sealing the adjacent end surfaces by a continuous weld 72. The thermocouple or fibre optic line 21 is preferably placed against the sheet metal and held away from the weld 72 during this welding process, so that the tubing 18 is effectively formed about the line, and so that the heat from the weld 17 does not damage the line 21. Figure 4 depicts line 21 comprising a relatively low cost outer

stainless steel sheath 74. For a thermocouple line, conductor wires 76 and 78 are positioned within the sheath and electrically isolated both from each other and the sheath by insulating material 80. For a fibre optic line, optical fibres are positioned within the sheath and may or may not be insulated from each other or the sheath 74. In the fibre optic system, the sheath 74 may be replaced with a suitable coating or wrapping. Various thermocouple lines and thermocouple junctions may be used in accordance with the present invention, although a suitable thermocouple line manufactured with a magnesium oxide insulating material, and utilizes an ungrounded measuring junction electrically isolated from the sheath end, which both protects the junction and minimizes stray electromotive force signals. A suitable fibre optic line may be sheathed or coated prior to being placed within tube 18, preferably in the manner as shown in Figure 4. A suitable coating will depend on the anticipated temperature within the tube 18, and coatings are available to withstand conditions of from -100°C to +600°C or more, especially since the line is protected by a non-hostile fluid. If desired, exotic and more expensive coating may be applied to the mid section of the fibre optic loop (which will be the lowermost portion of the installed fibre optic line), since the last few meters of the line within the assembly 29 and housing 19 may be unprotected by the tube 18.

Figure 5 depicts the fibre optic pressure and temperature system according to the present invention. The downhole components at assembly 29 may be similar to those previously described, except that further flexibility is permitted due to the multiple temperature point measurement characteristics of the optical system. In an embodiment as depicted in Figure 5, the fibre optic line 82 is housed within the tubing 18 and extends through fitting 34 to terminate within test housing 19 at a location in engagement with the well fluid 16. Since the fibre optic system allows for multiple point temperature measurements, however, a reliable well bore temperature profile and an accurate well bore pressure compensation signal may be generated even if the fibre optic line 82 does not engage the well fluid. For reasonable accuracy of the compensating correction signal, the fibre optic line should extend to a position reasonably close to the assembly 29, and preferably extends to a depth within two times the length of the test housing 19 from the top of the housing 19. Accordingly, the fibre optic line 82 could be provided entirely within the tubing 18 immediately above assembly 29 (in which case no special covering may be necessary for the lower portion of the line), could extend into engagement with the well fluid, or may terminate at some location therebetween.

Figure 5 depicts the tubing 18 exiting the well head 8 via fitting 9 as previously discussed. Manifold 20, valve 7, test fluid source 22, pressure measuring device 26 and the pressure readout 27 are each located on the surface, and were previously discussed. The fibre optic line 82 exits the manifold 20 unprotected by the tubing 18, and is shown to comprise optical fibres 84 and 86 structurally wrapped or coated by a suitable layer 88, although the optical fibers need not be isolated from each other. Also, Figure 5 illustrates additional fibre optic lines 82A and 82B extending to the temperature measuring device 24, and each of these lines may correspond to a line within a similar tubing 18 extending into an adjacent well bore. In one embodiment, device 24 comprises an optical front end device 90, a laser pulser 91, timer 92, electronics package 93, microprocessor 94, and detector 95. The timer 92 controls pulser 91 to intermittantly generate laser bursts which pass through the optical front end device 90. At each testing site, a portion of this laser pulse is reflected back to the surface, and is measured by detector 95. The timer 92, electronics 93 and microprocessor 94 cooperate to receive the output from the detector and determine the temperature at each of the test sites, as previously explained. Although it is preferred to have an optical fibre loop consisting of fibre 84 and 86 in line 82 for increased accuracy, a single optical fibre may be used in line 82 extending from device 24 to the downhole location adjacent the assembly 29. Also, a temperature sensing line within the tubing 18 other than a thermocouple line or a fibre optic line could possibly be used to measure downhole temperature according to the present invention.

One of the advantages of the present invention is that both temperature and pressure readings of the downhole fluid can be easily obtained at the surface, although only one line need be installed in the wellbore. With the fibre optic system, multiple borehole temperature measurements are obtained although the diameter of the tubing 18 need not be increased to accommodate multiple thermocouple lines, thereby increasing the versatility and accuracy of the system without a significant increase in costs. The utilization of one rather than two lines substantially increases the reliability of the system according to the present invention, since twisting problems normally associated with long lengths of two or more lines as they are lowered into the borehole are avoided. The questionable reliability of a system using multiple lines, as well as the delays and costs associated with repairing those systems, are thus avoided by the present invention since a single line is provided for reliably measuring both pressure and temperature.

It is a further advantage of the present invention that the thermocouple or fibre optic line is substantially protected by the inert test fluid in the small diameter tubing. Although the thermocouple or fibre optic line preferably is sheathed over its entire length so that no wires or optical fibres are exposed to the test fluid, the thermocouple or fibre optic line itself is not exposed to the hostile and generally corrosive borehole

environment. Test fluid is sealed at a location of the manifold which is outside of the wellhead, so that an electrical junction is not necessary either in the wellhead or in the borehole. Since the thermocouple or fibre optic line is substantially protected by the selected test fluid, the metal sheathing of the line 21 may be fabricated from stainless steel or other material which is substantially less expensive than exotic materials which are necessary for protecting the thermocouple wires or optical fibres from the corrosive and hostile borehole fluids.

While particular embodiments of the present invention have been shown and described, it is apparent that further changes and modifications can be made without departing from the spirit and scope of the invention. It is therefore the intention that the following claims cover all such changes and modifications.

Claims

1. Apparatus for measuring the pressure and temperature of a fluid in a borehole;
characterized by:
a tube (18) having a flow path extending continuously from the surface to a desired depth in the borehole;
a housing (19) defining a chamber (16) in fluid communication with both the borehole fluid and the flow path;
a pressurized test fluid source (22) at the surface for charging the flow path and a portion of the chamber with a test fluid to form an interface of the test fluid and the borehole fluid within the chamber (16);
a temperature sensing line (21) extending within said flow path from the surface towards the housing;
a manifold (20) at the surface and having a first port sealingly receiving the tube (18) with said line therein, a second port through which the line (21) extends from the manifold while sealing the test fluid within the manifold, and a third port through which test fluid can pass from the manifold;
pressure measuring means (26) at the surface in fluid communication with the third port to measure the pressure of the test fluid to permit determination of the fluid pressure at the desired depth; and
temperature measuring means (24) at the surface for receiving said line extending from the manifold (20) to permit determination of the temperature of the borehole fluid at the desired depth.

2. Apparatus according to claim 1 characterized in that said temperature sensing line (21) comprises a fibre optic line (82).

3. Apparatus according to claim 2 characterized in that said fibre optic line (82) comprises an optical fibre loop with its ends (84,86) at the surface.

4. Apparatus according to claim 2 or claim 3 characterized by a laser pulser (91) at the surface operable to intermittently transmit light pulses down the borehole through said fibre optic line (82); and a detector (95) at the surface for receiving pulses reflected back to the surface and providing signals representative of the borehole fluid temperature.

5. Apparatus according to claim 1 characterized in that said temperature sensing line (21) comprises a thermocouple line having a thermocouple junction (38) disposed within said chamber (16).

6. Apparatus according to any one of claims 1 to characterized by first and second axially spaced connector means (28,29) each in fluid-tight engagement with said tube (18) to interconnect the tube (18) and the housing (19).

7. Apparatus according to any one of claims 1 to 6 characterized by computing means (23) at the surface for receiving a temperature signal from the temperature measuring device (24) and supplying a temperature responsive correction signal to the fluid pressure as determined by said pressure measuring means (26).

8. Apparatus according to any one of claims 1 to 7 characterized in that the lower end of said temperature sensing line (21) is positioned within said chamber (16) in contact with the borehole fluid.

9. Apparatus according to any one of claims 1 to 8 characterized in that the test fluid is nitrogen or helium.

10. Apparatus according to any one of claims 1 to 9 characterized by a filter (36) disposed within the housing (19) to substantially prevent solids in the borehole fluid from passing into the tube (18), the filter having an opening through which the temperature sensing line (21) extends into the borehole fluid.

11. Apparatus according to any one of claims 1 to characterized in that said housing (19) is suspended in the borehole by production tubing (11) extending from the surface to the desired depth.

12. Apparatus according to claim 11 characterized in that said tube (18) extends down the borehole outside said production tubing (11), said production tubing having a port (17) at its lower end through which said tube (18) extends to enter said chamber (16).

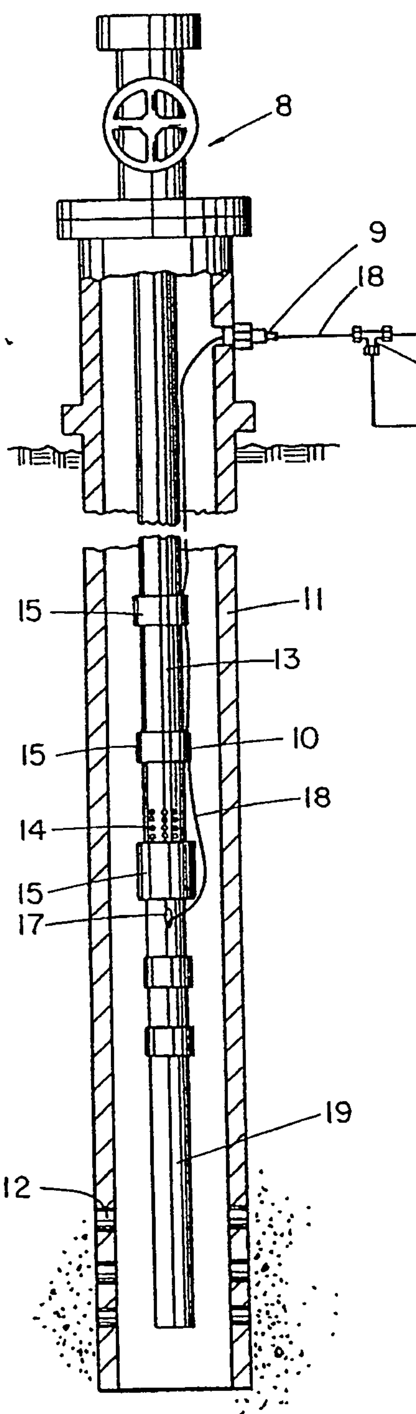
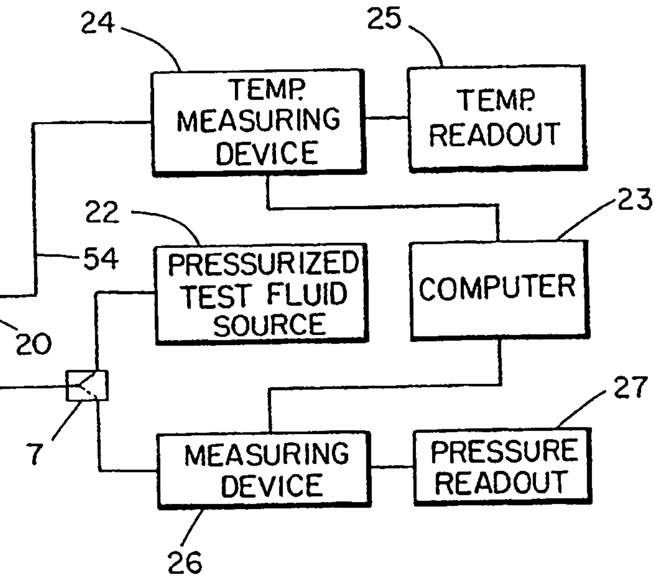
24
25
TEMP. MEASURING DEVICE
TEMP. READOUT
8
9
18
54
22
PRESSURIZED TEST FLUID SOURCE
23
COMPUTER
20
7
27
MEASURING DEVICE
PRESSURE READOUT
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FIG. 1

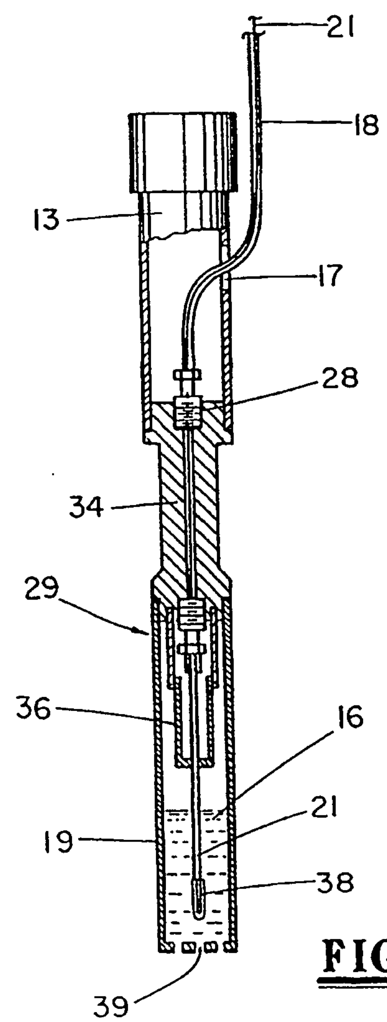
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FIG. 1A

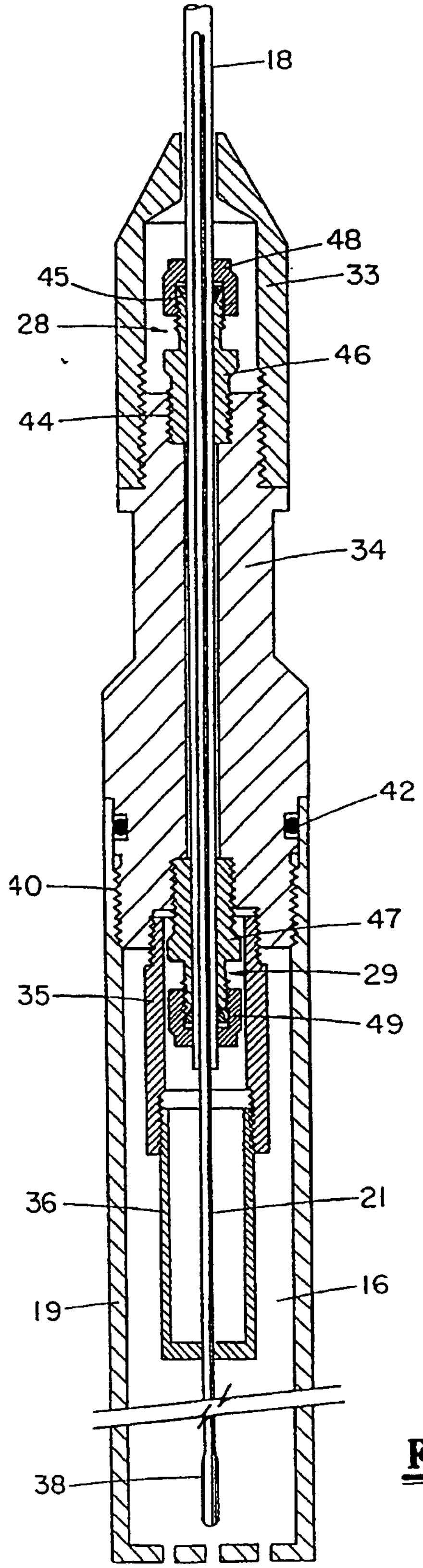


FIG. 2

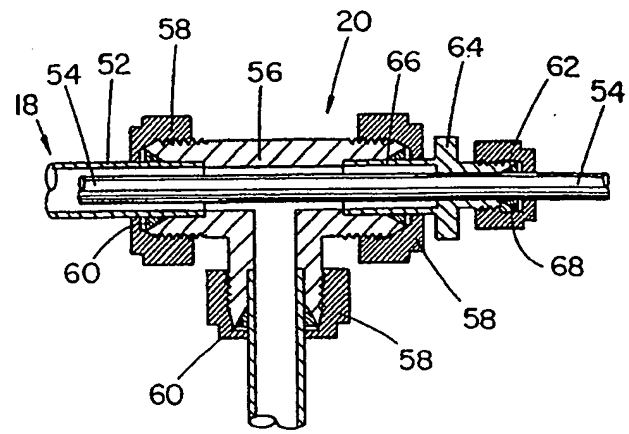


FIG. 3

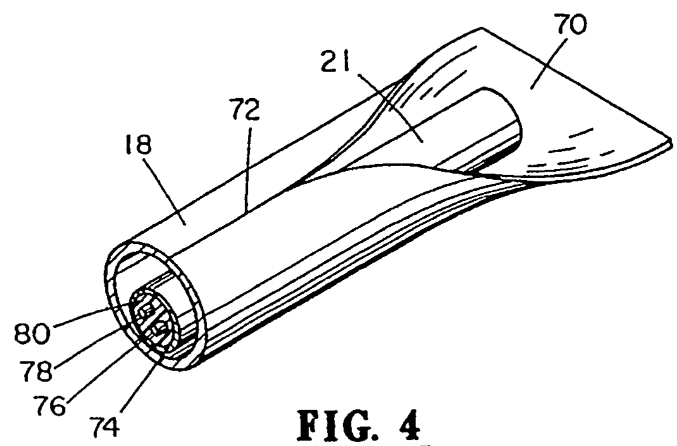
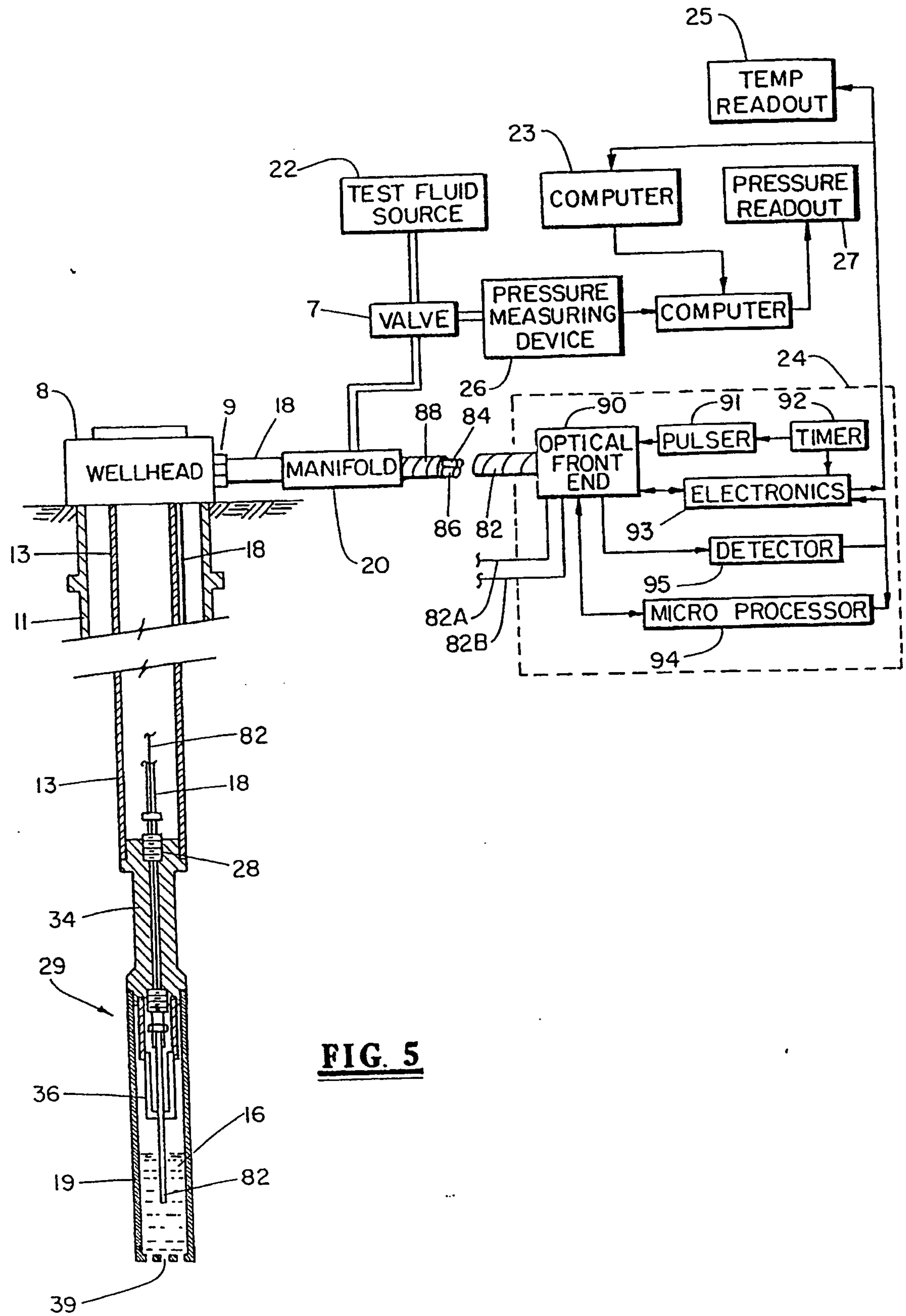


FIG. 4


25
TEMP READOUT
23
COMPUTER
PRESSURE READOUT
27
22
TEST FLUID SOURCE
7
VALVE
PRESSURE MEASURING DEVICE
COMPUTER
24
26
8
WELLHEAD
9
18
MANIFOLD
88
84
90
OPTICAL FRONT END
91
PULSER
92
TIMER
ELECTRONICS
93
DETECTOR
95
MICRO PROCESSOR
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82A
82B
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FIG. 5

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(54) Borehole pressure and temperature measurement system.

(57) A system is provided for measuring both the temperature and pressure of fluid in a borehole utilizing a single small diameter tube extending from the surface to the desired downhole test location in a borehole. Downhole fluid pressure is transmitted through the small diameter tube, while a sheathed thermocouple or fibre optic line extending along the flow path of the tube is used for transmitting downhole fluid temperature information to the surface. A continuous surface read-out of both pressure and temperature is thus possible, and the temperature read-out may be used to both monitor downhole fluid temperature and increase the accuracy of the fluid pressure measurement system.

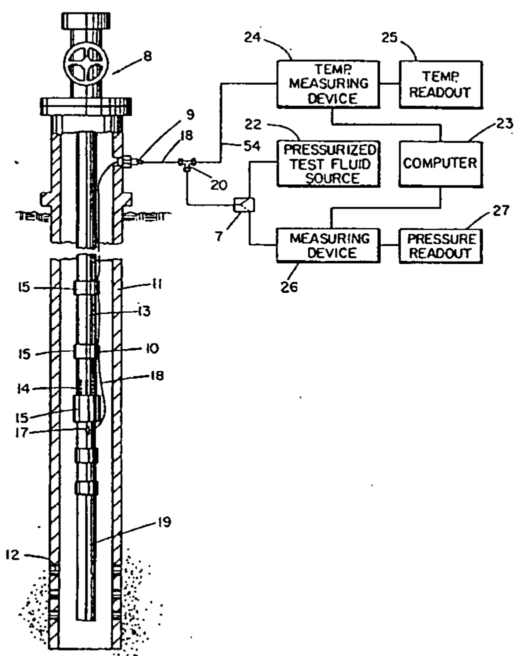

FIG. 1

EP 0 424 120 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 31 1393

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y,D	US-A-4 010 642 (MCARTHUR) * column 2, line 46 - line 66 * * column 3, line 21 - column 5, line 22; figures *	1-12	E21B47/06 E21B47/12
Y	US-A-4 375 164 (DODGE ET AL.) * column 6, line 42 - column 7, line 11; figures 6,7 *	1-12	
Y A	US-A-4 616 705 (STEGEMEIER ET AL.) * column 3, line 6 - line 34; figures 1,2 *	5 1	
Y A	US-A-4 252 015 (HARBON ET AL.) * column 4, line 3 - line 36; figures 2-5 *	6 1,10,11	
Y	US-A-4 427 941 (RIEDESEL,JR. ET AL.) * column 1, line 12 - line 20 *	7	
Y	FR-A-0 827 274 (SOCIETE DE PROSPECTION ELECTRIQUE SCHLUMBERGER) * page 1, line 1 - line 32; figure 1 *	8	TECHNICAL FIELDS SEARCHED (Int. Cl.5) E21B G01L G01K
A	US-A-4 505 155 (JACKSON) * column 4, line 43 - line 57; figures 1,2 *	1,10-12	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 FEBRUARY 1992	LINGUA D.G.

CATEGORY OF CITED DOCUMENTS

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